
Appendix D

TRE Case Study: City of Durham, North Carolina

Abstract

TRE Goal:	NOEC = 100%
Test Organism:	<i>C. dubia</i>
TRE Elements:	Toxicity treatability evaluation
Toxicant Identified:	TIE not performed
Toxicity Controls:	Proceeded with planned POTW upgrades

Summary

The City of Durham evaluated the expected toxicity reduction to be achieved by planned upgrades of their POTWs. Chronic toxicity reduction was evaluated through the use of bench-scale simulations of the upgraded POTWs. Results indicated that the new POTWs would reduce chronic toxicity to compliance levels. Based on this evidence, the TRE was waived until the new POTWs were online and effluent toxicity reduction could be confirmed. The upgraded POTWs became operational in late 1994 and effluent monitoring results have shown no chronic toxicity after consistent treatment performance was achieved.

Key Elements

The TRE study used a unique approach to evaluate chronic toxicity reduction. This approach may be useful to other municipalities that have TRE requirements, yet are planning upgrades of their POTWs. The key elements of interest in the City of Durham study include the following:

1. In cases where POTW staff are planning to upgrade their POTWs, it may be more practical to evaluate the toxicity reduction to be achieved by the upgrade than to conduct TIE tests on the existing POTW effluent. The treatability approach is recommended when the upgrade is expected to

improve toxicity reduction, such as nitrification treatment for ammonia removal; however, additional evidence is needed to confirm the expectation.

2. A bench-scale simulation of the upgraded treatment system can be used to generate an effluent that is similar to the effluent expected for the new POTW. Calibration tests should be performed to ensure that the quality of the simulation effluent is similar to that of the planned POTW effluent.
3. The treatability approach should be thoroughly described in the TRE plan and the regulatory authority should accept the plan prior to testing.

Introduction

Permit Requirements

Since 1987, NCDEM has required the City of Durham to monitor the effluents of its four POTWs for chronic toxicity using the North Carolina pass/fail test. The pass/fail test consists of 10 replicates of the effluent at the critical instream waste concentration (IWC) and a control. The effluent test concentrations corresponding to the IWC were 63.8% for the Eno River POTW, 100% for Lick Creek POTW, 98.7% for Farrington Road POTW, and 100% for Northside POTW. The test results indicated unacceptable levels of chronic effluent toxicity for each of the four POTWs. In each case, a statistically lower number of *C. dubia* young were observed in the effluent concentration as compared to the control.

Based on the effluent toxicity monitoring results, NCDEM required the City of Durham to initiate a TRE in January 1990. The goal of the TRE was to identify methods for reducing chronic effluent toxicity to acceptable levels at each of the treatment plants by

January 1991. The City of Durham submitted a plan within 60 days that described a unique approach for implementing the TRE program.

Instead of the traditional TRE approach of testing the existing effluents, the City proposed to evaluate the expected chronic toxicity reduction to be achieved by planned upgrades to the POTWs. Toxicity reduction would be evaluated through the use of bench-scale simulations of the upgraded POTWs. This approach was favored over conventional TRE methods, such as TIE tests, because it was anticipated that the degree and nature of the effluent toxicity would change upon startup of the new treatment plants.

Description of the Treatment Plants

In 1990, the City of Durham, North Carolina, had four POTWs: Eno River (2.5 mgd), Farrington Road (13 mgd), Lick Creek (1.5 mgd), and Northside (10 mgd). In anticipation of the need for additional treatment capacity, the City decided to close the Eno River and Lick Creek treatment plants and divert the flow to an expanded Northside plant. At the same time, NCDEM established draft permit limits for several parameters, including phosphorus. The new permit limits would require advanced wastewater treatment; therefore, in addition to the Northside plant expansion, the City of Durham decided to upgrade the Northside and Farrington Road POTWs plants to include BNR treatment.

During the TRE, the Northside POTW comprised primary treatment followed by trickling filters, a single-stage nitrification process, secondary clarification, and chlorine disinfection. The Northside POTW upgrade involved building a new treatment system in parallel with the existing system, which would treat the flow diverted from the former Eno River and Lick Creek plants. The new treatment system was planned to consist of primary clarifiers and a five-stage BNR process designed to remove nitrogen and phosphorus. Effluents from the new and existing treatment systems will be combined, treated with aluminum sulfate (alum), passed through a filtration process, and disinfected by UV light prior to discharge to Ellerbe Creek.

The Farrington Road POTW was planned to be converted from a two-stage nitrification process to a five-stage BNR process similar in design to that planned for the Northside plant. Final effluent

treatment, like the Northside plant, will involve alum treatment, filtration, and UV disinfection.

Wastewater Treatment Plant Simulations

The new treatment processes for the Northside and Farrington Road POTWs were planned to be similar; therefore, the simulation designs were nearly identical. A batch mode of operation instead of a continuous flow mode was selected to reduce study costs. Both simulations, as shown in Figure D-1, comprised a BNR process, followed by alum flocculation, settling, and effluent filtration. Phosphorus and nitrogen removal was achieved in the BNR process, which involved treating the influent wastewater with activated sludge in five consecutive stages (anaerobic, anoxic, aerobic, anoxic, and aerobic). The BNR process effluent was then treated with alum and passed through a dual media filter column to remove additional phosphorus. Chronic toxicity tests using *C. dubia* (USEPA, 1989) were performed on the final simulation effluents to evaluate the expected effluent quality of the full-scale treatment systems.

Simulation of the Northside POTW involved treating the combined influents of the three POTWs scheduled for consolidation: the Eno River, Lick Creek, and Northside plants. The influents were combined in proportion to their respective flow rates. The Farrington Road POTW influent was used directly in the simulation tests of the Farrington Road facility. Each simulation influent was settled for approximately 2 hours to simulate primary sedimentation.

The activated sludge used in the simulations was collected from a municipal treatment plant that had a BNR process similar to the system planned for the City of Durham POTWs. RAS was collected from the plant's clarifier return line and mixed liquor solids were collected from the aeration basins. RAS was mixed with the simulated primary effluent in the first BNR simulation stage (anaerobic). Phosphorus removal was enhanced in the subsequent BNR stages by replacing a portion of the RAS with nitrate rich, aeration basin sludge. The nitrate was an essential source of oxygen for phosphorus removing bacteria in the BNR anoxic stage.

Following biological treatment, the activated sludge was settled and the clarified effluent was withdrawn and treated with alum. Alum treatment involved flash mixing and settling. The clarified supernatant was then

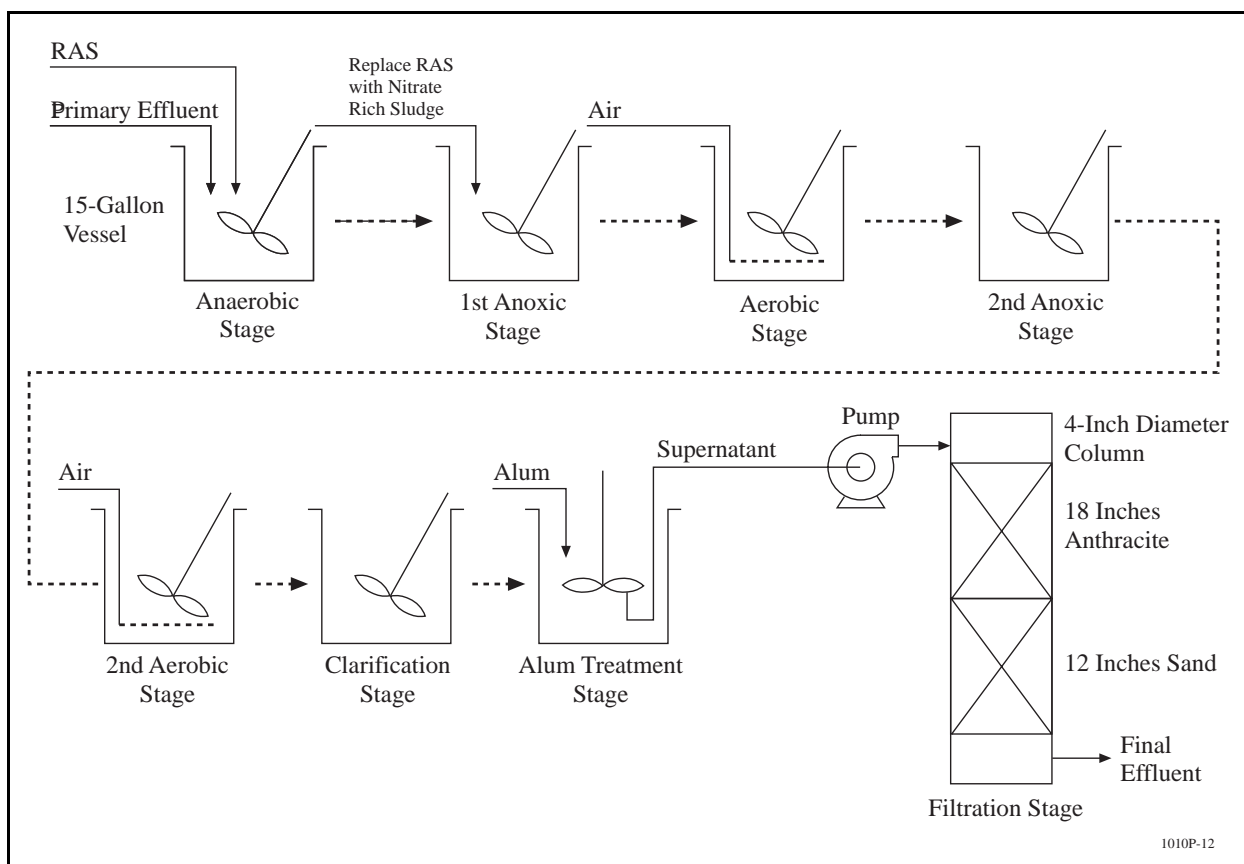


Figure D-1. Flow diagram for wastewater treatment simulations.

passed through an anthracite/sand filter column, which was operated in a constant headloss mode. Prior to testing, the anthracite and sand in the filter columns was distributed by backwashing the columns in the upflow direction using tap water. The filter columns were then rinsed with deionized water in the operational (downflow) mode.

The general operating conditions for the treatment simulations are shown in Table D-1. Some of the operating procedures for the simulations were modified during calibration testing to achieve the desired treatment performance.

Calibration of the Treatment Simulations

Prior to the toxicity evaluation, calibration tests were performed to match the simulation performance to expected performance for the upgraded POTWs. Also, several toxicity tests were performed during the calibration testing to verify that the simulation materials and additives (i.e., activated sludge, alum) would not introduce unexpected toxicity. The toxicity tests followed USEPA procedures (1989) for *C. dubia*, the test organism specified in the City's discharge permits.

The calibration testing involved varying the operation of the simulations and monitoring the resulting effluent quality. The objective was to achieve a reduction in influent concentrations of BOD₅, COD, TKN, NH₃-N, NO₃-N, TP, PO₄-P, and TSS to levels approximating those expected in the effluents of the planned treatment plants. Treatment performance was evaluated by varying the treatment times for each step.

The treatment times evaluated during the calibration testing were 90, 100, and 110% of the design HRT. A summary of the conventional pollutant results for the calibration study is shown in Tables D-2 and D-3. Also shown are the monthly average permit limitations and the design effluent characteristics for the planned facilities.

Biological Treatment

All BNR process simulations successfully achieved carbonaceous BOD₅ removal and nitrification. As shown in Table D-2, the batch biological process removed BOD₅, COD, and ammonia concentrations to well below design effluent levels. TKN concentrations in the simulation effluents also met the design levels.

Table D-1. Farrington Road and Northside Simulation Operating Conditions

Parameter	Farrington Road		Northside	
	POTW Design*	Simulation	POTW Design*	Simulation
Biological Treatment Step				
Primary effluent volume	24.5 mgd	100%		
Eno River			3.00 mgd	14.0% †
Lick Creek			6.94 mgd	32.3% †
Northside			11.53 mgd	53.7% †
Average MLSS	3,000 mg/L	3,508 mg/L	3,000 mg/L	3,481 mg/L
Minimum DO				
Anaerobic	0 mg/L	<0.2 mg/L	0 mg/L	<0.2 mg/L
1st Anoxic	0 mg/L	<0.2 mg/L	0 mg/L	<0.2 mg/L
1st Aerobic	2 mg/L	2 mg/L	2 mg/L	2 mg/L
2nd Anoxic	0 mg/L	<0.2 mg/L	0 mg/L	<0.2 mg/L
2nd Aerobic	4 mg/L	4 mg/L	4 mg/L	4 mg/L
Temperature (°C)	10–26	20–25	12–29	20–25
Alum/Filtration Treatment Steps				
Alum dose after biological treatment	10 mg/L	20 mg/L	5 mg/L	10 mg/L §
Depth of anthracite/sand in filter	8"/8"	8"/8"	18"/12"	18"/12"
Constant headloss level in filter	4 ft	4 ft	2–8 ft	4 ft
Average filtration rate	2.4 gpm/ft ²	2.4 gpm/ft ² ‡	4 gpm/ft ²	4.1 gpm/ft ² #

* Source: Hazen and Sawyer; R.L. Taylor, personal communication to J.A. Botts, *Design Information for the Treatment Plant Expansions*. December 10, 1990, Raleigh, North Carolina.

† Percent of total simulation influent volume.

‡ Filtration rate was 4.2 gpm/ft² for April 4–5 simulation.

§ Alum dosage increased to 20 mg/L for April 10–11 simulation.

Filtration rate was 7.1 gpm/ft² for April 4–5 simulation.

The BNR simulations did not consistently achieve the effluent permit levels for phosphorus (Table D-2). No phosphorus removal was observed in the April 4–5 test. For subsequent tests, the percentage of aeration basin sludge added to the anoxic stage was increased to stimulate phosphorus removal. This modification resulted in a decrease in phosphorus to near design levels in the April 10–11 test. As shown in Table D-3, phosphorus was initially released by the bacteria in the anaerobic stage, which is common in BNR systems. However, unlike the April 4–5 test, the phosphorus was re-assimilated in the anoxic and aerobic stages as

would be expected. These results demonstrated that phosphorus removal can be achieved in the batch simulation tests. The lack of phosphorus removal in the April 18–19 test appeared to be related to the poor quality of the activated sludge on the day of testing.

The BNR simulations also did not achieve consistent denitrification (Table D-2). The Northside simulation test on April 10–11 reduced nitrate to a level (1.7 mg/L) close to the design effluent concentration (1.0 mg/L). All other simulation tests achieved only slight nitrate removal. The lack of nitrate removal in

Table D-2. Comparison of Calibration Test Results to Permit Limitations and Design Criteria (mg/L)

Parameter	Monthly Average* Effluent Permit Limits	Design† Effluent Characteristics	Calibration Results		
			Apr 4–5	Apr 10–11	Apr 18–19
Northside POTW					
BOD ₅	24.0/12.0 ‡	5	1	1	1
COD	NA ‡	51	21	17	26
TSS	30	10	0	5	0
TKN	NA	1.5	1.5	1.5	0.9
NH ₃ -N	16.0/8.0 §	0.5	0.2	0.1	0.05
NO ₃ -N	NA	4.75	5.9	1.7	12.4
TP	2	0.5	6	0.8	6
Farrington Road POTW					
BOD ₅	10.0/7.0 ‡	5	1	1	1
COD	NA	45	23	26	23
TSS	30	10	1	5	2
TKN	NA	1.5	1.9	1	0.8
NH ₃ -N	4.0/2.0 ‡	0.5	0.1	0.1	0.1
NO ₃ -N	NA	1	7.1	6.5	14.7
TP	2	0.5	7.4	0.6	7.1

* Values are interim limits for the period beginning January 1, 1991, and lasting until 3 months after construction completion.

† Source: Hazen and Sawyer, R.L. Taylor, personal communication, to J.A. Botts, *Design Information for the Treatment Plant Expansions* December 10, 1990, Raleigh, North Carolina.

‡ Winter and Summer limits, respectively.

§ No limit established in permit.

the Farrington Road simulation may have been due to the short anoxic treatment time (approximately 3 hours) as compared to the Northside simulation (more than 4 hours). The simulation procedure was modified to increase the anoxic treatment time for the Farrington Road simulation to attempt to achieve denitrification during the effluent toxicity evaluation.

The toxicity test results indicated that the RAS supernatant used in simulation testing was not acutely toxic (LC50 ≥ 100%). Therefore, the activated sludge was not expected to cause an acute toxicity interference in the simulation tests.

Alum Treatment

As shown in Table D-3, only a slight removal of phosphorus was observed in the alum treatment step. Solids flocculation did not occur at the designed alum

dosages (10 mg/L for Farrington Road POTW and 5 mg/L for Northside POTW). Alum dosages were

Table D-3. Total Phosphorus Results (mg/L) for the Calibration Tests Conducted on April 10–11, 1990

Wastewater/Sludge	Farrington Road Simulation	Northside Simulation
Influent	5.49	3.95
RAS	13.5	13.5
Basin sludge	4.13	4.13
Biological treatment		
Anaerobic effluent	32.2	20.7
1st aerobic effluent	2.33	3.05
2nd aerobic effluent (Clarifier effluent)	1.48	1.78
Alum treatment supernatant	1.06	1.55

increased two-fold; however, no additional phosphorus removal was achieved.

The effect of alum on effluent toxicity was evaluated by comparing the toxicity of the wastewater before and after alum treatment. The results show that the alum did not add acute toxicity to the wastewater (i.e., LC50 >100% before and after alum addition).

Filtration Treatment

The filter columns were very efficient in removing suspended solids (Table D-2). As a result, nutrients and COD associated with the solids were further reduced. Total phosphorus concentrations decreased by nearly half after filtration (Table D-3).

The deionized water rinsates from the filter columns were analyzed for toxicity prior to testing. The results indicated that the filter media would not add acute toxicity to the simulation effluent (rinsate LC50 >100%).

Discussion of Calibration Results

The calibration results indicated that bench-scale tests could effectively simulate the effluent quality expected for the new POTWs. Pollutant removal was similar whether the simulations were tested at 90, 100, or 110% of the design HRT. BOD₅, COD, TKN, ammonia, and TSS were consistently reduced to levels expected to be achieved by the planned facilities. Although nitrate and phosphorus were not treated to design effluent levels, no adverse effects on toxicity treatment in the simulations were anticipated. The calibration results also indicated that the simulation materials would not contribute artifactual toxicity.

Toxicity Treatment Evaluation

Tests of the calibrated simulations were performed to determine if the new POTWs would eliminate chronic toxicity. The operating parameters for the simulations were based on the design HRT treatment condition (100%). An exception was the treatment time for the second anoxic treatment stage of the Farrington Road simulation, which was increased to stimulate denitrification. In addition, the alum dosages for both simulations were increased to enhance the flocculation necessary for phosphorus removal.

The treatment plant simulations were implemented on two occasions. Performance criteria were applied to ensure that the effluent quality was sufficient for toxicity evaluation. These criteria, shown in

Table D-4, were based on the treatment performance that was consistently achieved in the calibration tests.

Treatment Performance Results

A summary of the conventional pollutant results for the simulation effluents is shown in Table D-4. The results show that the simulations consistently achieved the design effluent concentrations for BOD₅, COD, TSS, and ammonia. Effluent TKN concentrations were within the simulation performance criterion of 5 mg/L. The effluent concentrations of total phosphorus and nitrate also were within the simulation performance criteria levels. Overall, the simulation effluents were judged to be suitable for toxicity analysis based on the simulation performance criteria.

Toxicity Evaluation Results

Results of toxicity tests, presented in Table D-5, show that the simulation effluents were not acutely toxic to *C. dubia* (48-hour LC50 ≥ 100% effluent). Chronic toxicity results show that the simulation effluents did not inhibit *C. dubia* reproduction (NOEC of 100% effluent). Only the effluent of the Farrington Road simulation on May 29–30, 1990, adversely affected *C. dubia* survival (NOEC = 75% effluent). The chronic toxicity of this effluent was due to significant mortality in the 100% effluent concentration.

Sulfide was detected in the May 29–30 Farrington Road simulation effluent at a concentration that may be chronically toxic to *C. dubia* (1.6 mg/L). The sulfide NOEC for *D. magna* at pH 7.6–7.8 is reported to be 1.0 mg/L (USEPA, 1990). Although the toxicity of sulfide to *C. dubia* is unknown, the sensitivities of *D. magna* and *C. dubia* to many classes of toxicants are similar (Mount and Norberg, 1984). The pH values of the Farrington Road simulation effluent and the value used for the reported test also were similar (i.e., 7.85 versus 7.6 to 7.8); therefore, the potential toxicity of sulfide in the simulation sample should be comparable to that of the reported test (Note: the concentration of hydrogen sulfide, the most toxic form of sulfide, increases when pH decreases). Based on this evidence, the chronic toxicity observed in the May 29–30 Farrington Road simulation effluent may be related to sulfide.

Discussion

The TRE study was completed within the 1-year time frame specified by NCDDEM. The results of this study indicated that the addition of new BNR and filtration treatment processes at the City of Durham POTWs

Table D-4. Comparison of Simulation Test Results to Performance Criteria

Parameter	Simulation Performance Criteria (mg/L)*	Simulation Effluent Results (mg/L)	
		May 29–30	June 6–7
Northside POTW			
BOD ₅	5	1	1
COD	51	22	21
TSS	10	3	2
TKN	5	2	NA †
NH ₃ -N	0.5	0.1	0.1
NO ₃ -N	15	5.5	11.3
TP	8	1.2	3.2
Farrington Road POTW			
BOD ₅	5	1	1
COD	45	22	22
TSS	10	4	1
TKN	5	2.3	NA
NH ₃ -N	0.5	0.1	0.1
NO ₃ -N	15	5.2	9.3
TP	8	1.5	3.8

* Simulation performance criteria based on calibration results and design effluent levels (Hazen and Sawyer; R.L. Taylor, personal communication, to J.A. Botts, *Design Information for the Treatment Plant Expansions*. December 10, 1990, Raleigh, North Carolina).

† NA = not available.

Table D-5. Toxicity of Simulation Effluents to *C. dubia**

Date	Simulation	48-hour LC50 (%Effluent)	NOEC † (%Effluent)	LOEC ‡ (%Effluent)
May 29–30, 1990	Farrington Road Northside	100	75 §	100 §
		>100	100	>100
June 6–7, 1990	Farrington Road Northside	>100	100	>100
		>100	100	>100

* 7-day chronic toxicity test (USEPA Method 1002.0) according to USEPA (1989).

† NOEC for Northside is based on survival and reproduction. Results for Farrington Road are based on survival.

‡ LOEC for Northside is based on survival and reproduction. Results for Farrington Road are based on survival.

§ Denotes statistically significant inhibition of survival.

would reduce chronic effluent toxicity to levels required under the North Carolina discharge permit. Sulfide, a potential effluent toxicant, was not expected to be a problem because the final effluents of the new treatment plants are aerated to meet instream DO standards. The sulfide should be volatilized or oxidized in this aeration step.

The POTW upgrades were implemented beginning in November 1994. Results of effluent monitoring through the second quarter of 1997 show that the POTWs are in compliance with the chronic toxicity limits. The limits were revised to NOECs ≥90% for both plants. One test failure was observed in January 1995; however, this result may have been related to the

start-up of the new treatment processes. Since then, the City has passed all quarterly tests at both POTWs.

Bench-scale batch tests were successfully used to simulate the treatment processes planned for the new POTWs, including the BNR treatment process. In addition to carbon removal and nitrification, the simulations achieved phosphorus removal to near permit levels. Although nitrate was not reduced to permit levels, the observed concentrations did not cause chronic toxicity.

The study findings suggest an alternative TRE approach is appropriate in cases where POTW staff is planning upgrades or improvements to their WWTPs. Toxicity reduction can be evaluated by conducting bench-scale batch simulations of the planned upgrades. This testing can be used to determine the potential for compliance with discharge limits for toxicity. If non-compliance is anticipated, further testing can be performed to evaluate the additional improvements necessary for toxicity reduction. In cases where the conclusions of a bench-scale toxicity evaluation are uncertain, pilot-scale tests may be warranted.

Acknowledgments

The City of Durham TRE study was conducted by Engineering-Science, Inc., under contract to Hazen and Sawyer, P.C., and the City of Durham. The assistance of A.T. Rolan, W.W. Sun, Vicki Westbrook, and Susan Turbak (City of Durham); Linda Forehand, Tim Morris, Jim McReynolds, and Tory Champlin (Engineering-Science, Inc.); and William L. Goodfellow (EA Engineering, Science and Technology, Inc.) are acknowledged.

The material presented in this appendix includes copyrighted information published in text by

Technomic Publishing Company, Lancaster, Pennsylvania (Botts et al., 1992). Technomic Publishing Company has granted permission to include the information in this document.

References

- Botts, J.A., T.L. Morris, J.E. Rumbo, and C.H. Victoria-Rueda. 1992. Case Histories-Municipalities. In *Toxicity Reduction: Evaluation and Control*. D.L. Ford, ed. Technomic Publishing Co., Lancaster, Pennsylvania.
- Engineering-Science, Inc. 1989. *Test Plan for the City of Durham Toxicity Reduction Evaluation Project*. Prepared for the City of Durham, North Carolina.
- Engineering-Science, Inc. 1990. *Results of the Development and Implementation of Wastewater Treatment Plant Simulations for the City of Durham TRE*. Prepared for the City of Durham, North Carolina.
- Mount, D.I., and T.J. Norberg. 1984. A Seven-Day Life Cycle Cladoceran Test. *Environ. Toxicol. Chem.* 3: 425-34.
- USEPA. 1989. *Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Water to Freshwater Organisms*. Second Edition. EPA/600/4-89/001. Office of Research and Development, Cincinnati, Ohio.
- USEPA. 1990. *Aquatic Information Retrieval Toxicity Data Base*. Office of Research and Development, National Health and Environmental Effects Research Laboratory, Mid-Continent Ecology Division, Duluth, Minnesota.